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A NOTE ON THE OPTIMUM AVERAGING TIME OF WIND INFORMATION FOR CONVENTIONAL AIRCRAFT LANDINGS

By W. R. SPARKS and BARBARA KEDDIE

Summary. From detailed analysis of wind measured by a single anemometer 10 metres above open level ground, and consideration of Shiotani's observations with a horizontal array of anemometers, it is concluded that the optimum averaging time for wind measured by a single anemometer should not be less than four minutes.

Introduction. At some stage during an aircraft approach it is necessary to pass to the pilot the wind expected in the touch-down area at the time his aircraft will reach that area. Since it is not possible to site a conventional anemometer in the touch-down area this necessitates the extrapolation of measured wind information in both time and space, and prompts the question : what can be measured with the normal airfield anemometer to give the best estimate of the wind that an aircraft will encounter in a different position and at a later time?

Before it is possible to begin to answer that question, what information the pilot requires must be known. There is no general agreement on this, but discussions with aviation experts suggest that the average wind over a period of 4 or 5 seconds just before touch-down when the aircraft is descending from about 30 m to 15 m is of critical importance. During that period the aircraft would travel about 300 m. If the validity of Taylor's hypothesis of frozen turbulence is assumed (Panofsky *et alii*[1]), the analogous measurement from a stationary anemometer is the average speed of a 300-m run of wind (U_{300}).

Let the wind measured at the anemometer be averaged over a time T to obtain a value U_T and that average be used as an estimate of U_{300} at some later time. How wrong can it be? A good measure of the errors is the root-mean-square difference between U_{300} and U_T divided by σ_{300}, the standard deviation of U_{300} over N observations, i.e.

$$(1/\sigma_{300})\sqrt{\Sigma\,[(U_{300}-U_T)^2/N]}.$$

Results and discussion. From observations made with an anemometer 10 m above flat open country at Cardington (near Bedford), the above ratio

has been calculated for averaging times T from ½ minute to 15 minutes. (The observations are described in Appendix I.) The ratio does of course depend on the interval between the observation of U_T and the time that U_{300} is required, see Appendix II. Two intervals have been considered, 10 minutes and zero minutes. The results of these calculations are shown n Figure 1.

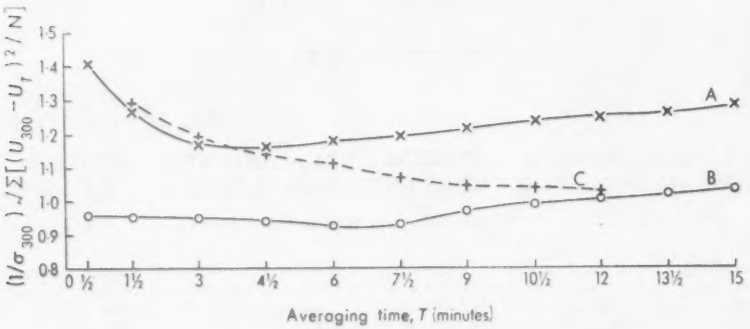

FIGURE 1—ERRORS IN ESTIMATING U_{300} FROM U_T (AVERAGED OVER SIX DATA RUNS)

A For a 10-minute interval between U_T and U_{300}
B For a zero time interval between U_T and U_{300}
C Theoretical curve for zero correlation between short-period means at two points

Curve A, which gives the results when there is a 10-minute interval between the observation and its use, i.e. between the end of the averaging time T and the beginning of the run of wind, shows that the minimum error is made when an averaging time of 4 to 5 minutes is used. Curve B shows that even when the information is used immediately after the observation, no increased accuracy is obtained by reducing the averaging period to any less than the 4 minutes suggested by curve A.

Curves A and B show the results that would be obtained if the anemometer could be sited in the touch-down area. Consider now the effect of measuring some distance from that area. The reduction in accuracy is a function of the correlation between the wind at the measuring point and the wind in the area of interest. This correlation depends on the separation between the instrument site and the area of interest and the averaging periods used.

On a normal airfield the anemometer would be several hundred metres from the touch-down area. The results from Shiotani's[2] observations with a horizontal row of anemometers suggest that the correlation between the airfield anemometer's indication of short-period means and simultaneous observations in the touch-down area could well be zero.

Curve C, determined as in Appendix II, shows the errors in estimating U_{300} in the touch-down area if the long-period means (say hourly running means) at the anemometer and in the touch-down area are equal and constant but the variations of the short-period means about the long-period mean

are uncorrelated at the two points. The variances of U_{300} and U_T used to construct curve C were the values measured at Cardington during Run No.3 (see Appendix I).

If the anemometer is sited a considerable distance from the touch-down area, curve C is applicable and it can be seen that any attempt to use an averaging period of less than the 4 minutes suggested by curve A would increase the errors even if the information were used immediately after the observation.

It has been demonstrated that, even if the wind information required by the pilot is a mean over a shorter period, the best estimate of the required information that can be obtained from a conventional anemometer is a mean value over a period of at least 4 minutes. It would also be possible, and may be desirable, to give the pilot some measure of the uncertainty of the estimate.

Although these conclusions are based on limited data (Appendix I) they are in excellent agreement with those of Rijkoort and Wieringa[3] and it is reasonable to assume that they are applicable to the well-stirred conditions in neutral equilibrium which accompany strong winds near the ground. The sudden arrival of squalls associated with the near approach of thunderstorms or the passage of a cold front would probably prove to be a source of large errors, but such errors would be expected in any method relying on observations from a single anemometer. There is however, a need for information on the effects of spatial separation between the anemometer site and the touch-down area.

Appendix I

Description of data analysed. The data were obtained from a three-cup anemometer with a distance constant of 5 m and a wind vane with a sine/cosine potentiometer. The data analysed were the westerly components of winds from directions between 240 degrees and 280 degrees. The anemometer was sited 10 m above open level country at Cardington. The site was fully described by Giblett[4] in 1932 and has not changed significantly since that time. The data were logged on 31 March 1969. During most of the period Cardington was in a warm sector and the winds were sufficiently strong to ensure near neutral stability. The mean wind was not, however, steady; during one data run it changed by about 10 kt in three minutes.

The data were logged at one-second intervals with each data run lasting about 50 minutes. The main features of the wind during each run are shown in Figure 2 by plots of consecutive one-minute means for Runs 2, 3 and 5. The features of Runs 1, 4 and 6 are similar to those of Run 3.

Figure 1 (page 130) shows average values over all six runs of the ratio

$$(1/\sigma_{300})\sqrt{\Sigma[(U_{300}-U_T)^2/N]}.$$

Figures 3 and 4 show the same information for individual runs.

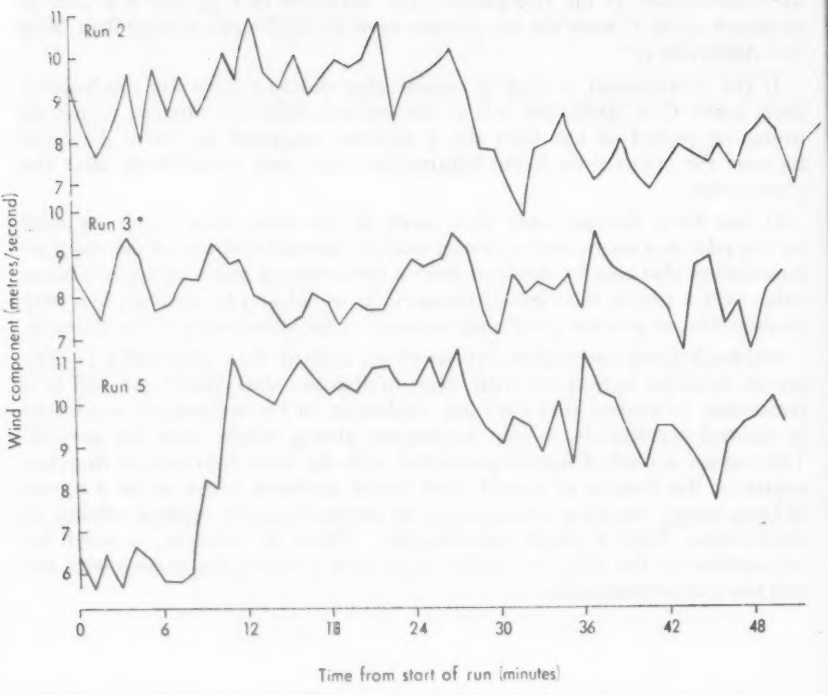

FIGURE 2—ONE-MINUTE MEANS OF THE WESTERLY COMPONENT FOR RUNS 2, 3 AND 5

* Runs 1, 4 and 6 show similar features.

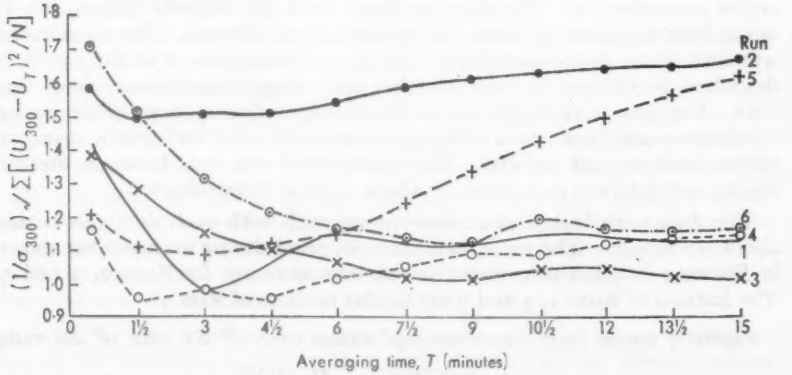

FIGURE 3—ERRORS IN ESTIMATING U_{300} FROM U_T FOR A 10-MINUTE INTERVAL BETWEEN THE TWO OBSERVATIONS

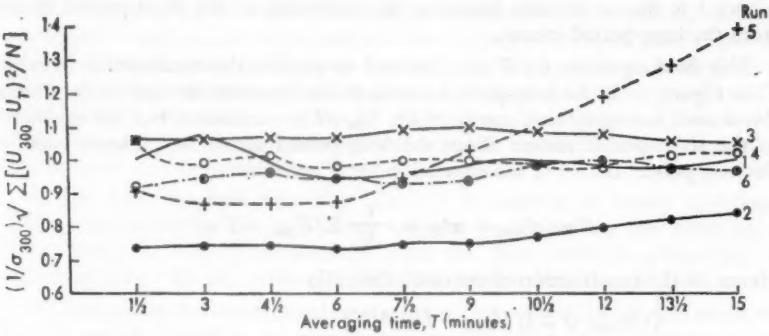

FIGURE 4—ERRORS IN ESTIMATING U_{300} FROM U_T FOR A ZERO TIME INTERVAL BETWEEN THE TWO OBSERVATIONS

Appendix II

The construction of the theoretical curve for zero correlation between short-period means at two points. U_T can be expressed as the sum of a long-term mean U_M appropriate to the mid-point of the interval T and the departure U'_T from that mean, i.e. $U_T = U_M + U'_T$.

Also U_{300} can be expressed as the sum of a long-term mean U_m appropriate to the mid-point of the interval of time for U_{300} and the departure U'_{300} from that mean, i.e. $U_{300} = U_m + U'_{300}$.

Consider the term

$$F = \frac{1}{N}\Sigma(U_{300} - U_T)^2,$$

where N is the number of observations of U_{300};

$$F = \frac{1}{N}\Sigma(U_m - U_M + U'_{300} - U'_T)^2$$

$$= \frac{1}{N}\Sigma(U_m - U_M)^2 + \frac{2}{N}\Sigma(U_m - U_M)(U'_{300} - U'_T) + \frac{1}{N}\Sigma(U'_{300} - U'_T)^2.$$

The second term will be zero if the difference between the two departure terms is not correlated with the trend in the long-term mean.

Then $$F = \frac{1}{N}\Sigma(U_m - U_M)^2 + \frac{1}{N}\Sigma(U'_{300})^2 + \frac{1}{N}\Sigma(U'_T)^2 - \frac{1}{N}\Sigma 2\,U'_{300}U'_T$$

$$= \frac{1}{N}\Sigma(U_m - U_M)^2 + \sigma^2_{300} + \sigma^2_T - 2r\sigma_{300}\sigma_T,$$

where r is the correlation between the variations of the short-period means from the long-period means.

This final equation for F may be used to explain the construction of curve C in Figure 1. If the long-period means at the anemometer and in the touch-down area are equal and constant, i.e. $U_m = U_M = \text{constant}$, but the variations of the short-period means about the long-period means are uncorrelated at the two points, i.e. $r = 0$, the expression for F becomes

$$F = \sigma^2_{300} + \sigma^2_T = \frac{1}{N} \Sigma (U_{300} - U_T)^2.$$

Hence in the construction of curve C, the ratio

$$(1/\sigma_{300}) \sqrt{\Sigma [(U_{300} - U_T)^2/N]}$$

becomes

$$\sqrt{(1 + \sigma_T^2/\sigma_{300}^2)}.$$

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SOME ASPECTS OF WIND INFORMATION REQUIRED IN THE LANDING OF AIRCRAFT

By BARBARA KEDDIE

Summary. Wind measurements were made each second with a single anemometer over a period of about an hour for six independent wind régimes. Detailed analysis was made of the maximum difference between a mean speed U_T measured over 4½ minutes and the speed U_{300} 10 minutes later over a 300-m run of wind. The maximum value of $U_{300} - U_T$ in various samples of sizes from 4 to 20 minutes was predicted by assuming a normal distribution. Theoretical curves were derived which were in reasonable agreement with curves drawn from the analysed data. Actual values were also compared with predicted values of (i) maximum deviation of $U_{300} - U_T$ from the mean in various samples, and of (ii) the maximum difference in various samples.

Finally comparison was made of data from different sampling periods or runs of wind so that if the maximum departure of one sample from the mean wind was known the maximum departure for other samples could be estimated.

Introduction. Pilots and others concerned with the operation of aircraft need a description of the airfield low-level wind which is used as a forecast of the wind expected a few minutes later as an aircraft touches down. At present the pilot is given the 'surface wind' by the controller about 10 minutes before touch-down. The problem is to find what information could be given to the pilot which would best describe conditions 10 minutes later.

The behaviour of the wind in the last 30 m of descent, in particular between 30 m and 15 m, is most important to a descending aircraft whether a manual or an automatic landing is being carried out. An aircraft normally travels about 300 m while descending from 30 m to 15 m, thus the 300-m run of wind defines one scale of eddy of importance to aviation. Therefore it would be useful to find a measurement which is representative of the 300-m run of wind 10 minutes later.

It has been assumed here that Taylor's hypothesis of frozen turbulence holds. According to this hypothesis a space correlation in the direction of mean wind, x, can be determined from the time correlation function by replacing time t by x/u, where u is the mean wind speed (Panofsky[1]).

By comparing the mean speed over a 300-m run of wind with that measured over a period T ending 10 minutes earlier, for values of T between $1\frac{1}{2}$ and 15 minutes, the optimum averaging time T has been found to be at least 4 to 5 minutes (Sparks and Keddie[2]). For the limited data considered here, the best estimate of the mean wind speed over 300 m to be expected in 10 minutes' time was taken to be the mean speed over the last $4\frac{1}{2}$ minutes, as longer averaging times did not appear to give an improvement in the accuracy of the estimate.

A pilot also requires information on the gustiness of the wind, but the anemometers in general use on airfields cannot measure gusts on a very small linear time-scale. At Cardington there is an anemometer placed 10 m above flat open country from which a read-out every second can be obtained (see Sparks and Keddie, Appendix I). By adding together the run of wind for successive seconds until a 300-m run has been obtained and dividing by the number of seconds, the mean wind speed over a 300-m run of wind can be found. Similarly mean speeds can be found for other lengths of run of wind. By comparing the wind extremes for different runs of wind a relationship might be determined whereby, if the maximum speed of one run of wind was measured, that of a different run of wind could be estimated.

Data available. The data used were obtained during six Runs at Cardington on 31 March 1969; details are given in Table I. A warm front passed through the station just after 08 GMT and the associated cold front passed between 17 and 18 GMT followed by a trough soon after 19 GMT, i.e. near the start of Run 5. The data consist of a read-out every second of the westerly component for winds from between 240 and 280 degrees, measured in metres per second at a height of 10 m (see Sparks and Keddie, Appendix I).

TABLE I—DATA OBTAINED DURING SIX RUNS AT CARDINGTON ON 31 MARCH 1969

Run number	Start time GMT	Duration *min*	*s*	Mean speed *m/s*	Mean direction *degrees true*
1	1313	48	19	13·7	240
2	1555	55	56	12·0	240
3	1702	52	28	11·2	245
4	1805	52	58	10·5	245
5	1906	53	0	11·7	260*
6	2004	52	55	11·2	265

* Discontinuous, 250° at first becoming 270° after 3 minutes gradually backing to 255° by 1945 GMT.

For successive 300-metre runs of wind the mean speed U_{300} was found and compared with U_T, the mean wind speed over a 4½-minute period ending 10 minutes earlier. The mean of the differences $(U_{300}-U_T)_m$, and standard deviation of the differences σ_{300-T}, were calculated for each Run. If the differences are normally distributed a prediction within given confidence limits can be made of the maximum $(U_{300}-U_T)$ likely in a given period with a steady régime.

Comparison of values predicted for the maximum $(U_{300}-U_T)$, assuming a normal distribution, with those actually obtained. Assuming a normal distribution, the probable maximum value of $(U_{300}-U_T)$ in a sample of N values may be defined either as (i) the value likely to be equalled or exceeded once in a sample of N (Durst[3]), or as (ii) the value likely to be exceeded once in a sample of $2N$ (Brooks and Carruthers[4]).

Samples of 8, 16, 24 and 32 values of $(U_{300}-U_T)$ were considered, 30 random samples of each size being taken for each Run. The mean maximum of $(U_{300}-U_T)$ was found for each set of 30 samples and standardized by subtracting $(U_{300}-U_T)_m$ and dividing by σ_{300-T} to facilitate comparisons with predictions based on normal distributions. Figure 1 shows the results together with curves, normal (1) and normal (2), determined from the normal distribution for definitions (i) and (ii) of the probable maximum value.

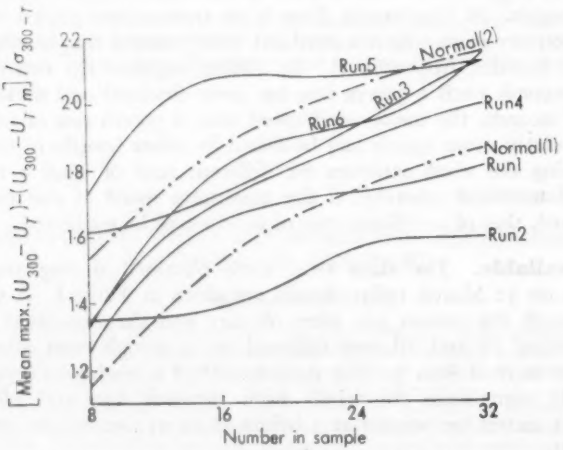

FIGURE 1—COMPARISON OF MEAN MAXIMUM $(U_{300}-U_T)$ OBTAINED IN RANDOM SAMPLES OF VALUES OF $(U_{300}-U_T)$ WITH THE MAXIMUM PREDICTED ASSUMING A NORMAL DISTRIBUTION

Definition (i) is perhaps more appropriate to the way in which the maximum is found from the samples. The curves are seen to be in reasonable agreement, except for Runs 2 and 5. Near the beginning of Run 5, there was a large increase in wind speed, about 10 kt in 3 minutes, and therefore there were some values of $(U_{300}-U_T)$ at the beginning of the Run which were much larger than the mean. The probability of one of these large values being included in a random sample is quite high, especially in the larger samples,

and so the 'mean maximum' is likely to be high. On the other hand, in Run 2 there was a decrease in wind speed in the middle of the Run, leading to several large negative values of $(U_{300}-U_T)$. This lowered the value of the mean maximum and also led to a large standard deviation, and hence the values plotted for Run 2 seem abnormally low.

Thus it seems reasonable to assume a normal distribution, at least in cases where there are no rapid and permanent changes of the wind, and to use definition (i). However, in practice it is not random values of $(U_{300}-U_T)$ that one is concerned with, but the maximum gust which is likely in a certain length of time, or in a certain number of consecutive values of $(U_{300}-U_T)$. Since a 300-m run of wind took from 30 to 40 seconds, sample sizes of 8 to 32 consecutive runs of wind represent time intervals of from about 4 to 20 minutes, which is adequate for the consideration of prediction for 10 minutes ahead. Figure 2 shows the results obtained using samples of 8, 16, 24 and 32

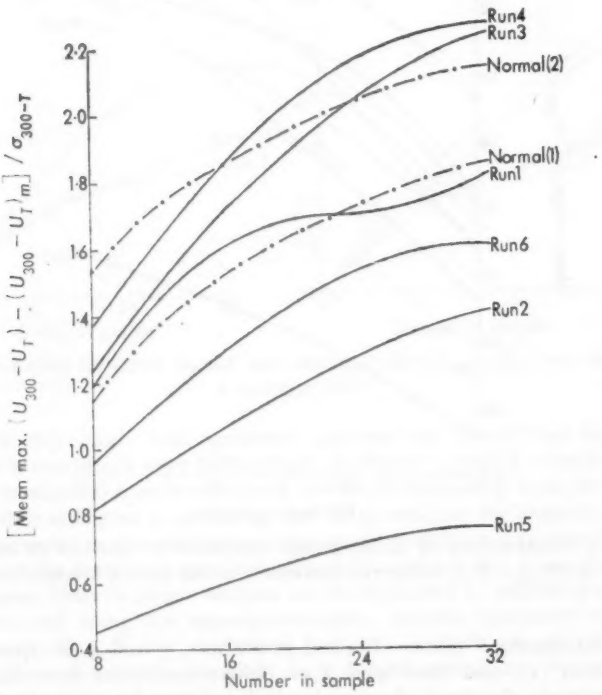

FIGURE 2—COMPARISON OF MEAN MAXIMUM $(U_{300}-U_T)$ OBTAINED IN SAMPLES OF CONSECUTIVE VALUES OF $(U_{300}-U_T)$ WITH THE MAXIMUM PREDICTED ASSUMING A NORMAL DISTRIBUTION

consecutive values of $(U_{300}-U_T)$. The number of samples of each size varied as the Runs were not all of the same length; for the shortest Run there were 23 samples of 8, 19 of 16, 15 of 24, and 11 of 32; and for the longest Run there were 34 samples of 8, 30 of 16, 26 of 24, and 22 of 32. The curves are not in

very close agreement with either of the normal curves, although they show a similar shape. The lack of agreement could be because of changes in the mean wind speed over the Run. To overcome this effect the range was considered instead of just the maximum value, i.e. for each sample the difference between the maximum and minimum values of $(U_{300}-U_T)$ was found and the mean taken over a number of samples. By dividing this mean range by twice the standard deviation, σ_{300-T}, standardized curves can be obtained (Figure 3) which can be compared with the normal curves used in Figures 1 and 2.

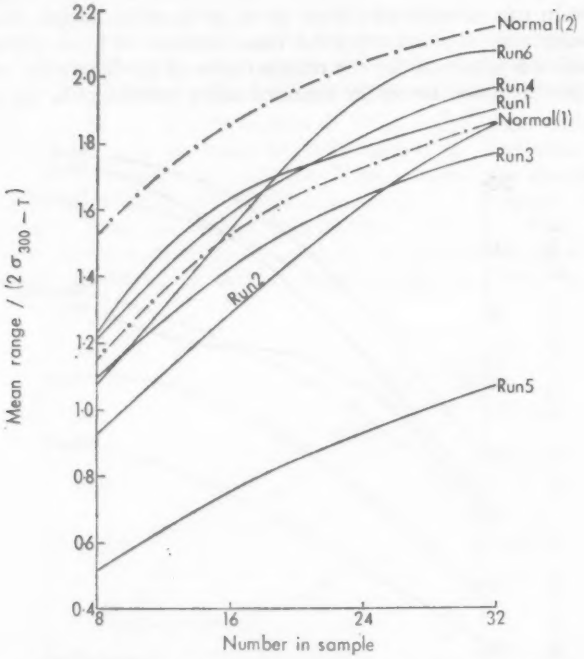

FIGURE 3—COMPARISON OF MEAN RANGE OBTAINED IN SAMPLES OF CONSECUTIVE VALUES OF $(U_{300}-U_T)$ WITH THAT PREDICTED ASSUMING A NORMAL DISTRIBUTION

The standardized curves obtained in Runs 1, 3 and 4 are quite close to the normal (1), and these were Runs where conditions were fairly steady. Run 5 is again abnormal, the very low values being due to the large standard deviation.

Although the values in Figures 2 and 3 are in some cases rather far from the normal, the slopes of the curves appear to be similar, implying that the ratios of points on the curves are similar for each Run. Figures 4 and 5 show the ratios of values for samples of 16, 24, and 32 to those for samples of 8, corresponding to Figures 2 and 3 respectively, for each Run and for the normal curve (1). The agreement between all the Runs and the normal in

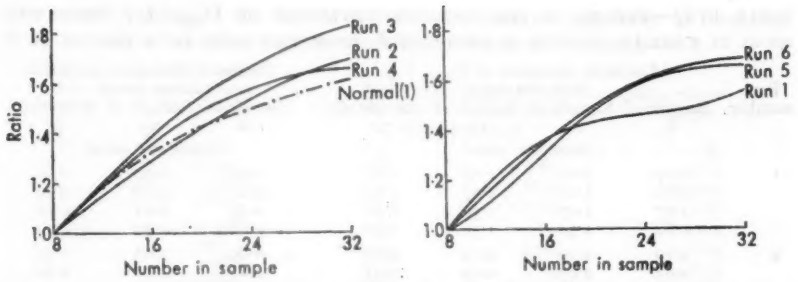

FIGURE 4—RATIO OF MAXIMUM DEPARTURE OF $(U_{300}-U_T)$ FROM THE MEAN FOR DIFFERENT SIZED SAMPLES TO THAT FOR A SAMPLE OF 8

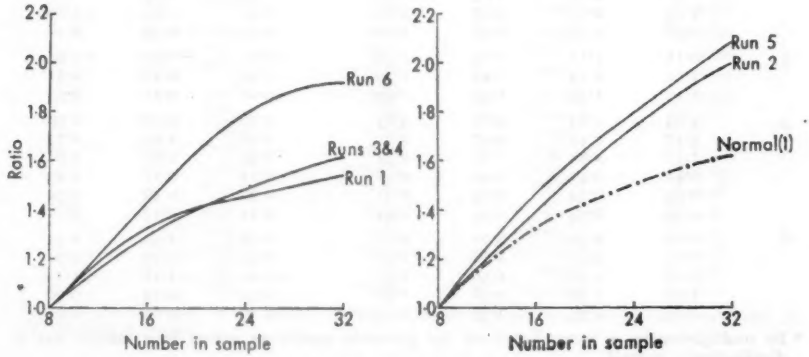

FIGURE 5—RATIO OF MEAN RANGE FOR SAMPLES OF $(U_{300}-U_T)$ TO THAT FOR A SAMPLE OF 8

Figure 4 is very good. The agreement between the normal and Runs 1, 3 and 4, when conditions were fairly steady, in Figure 5 (which considers range instead of maximum) is extremely good, but for the remaining Runs the result is not as good as in Figure 4, indicating that for general use the range is not such a good parameter as the maximum value as far as ratios are concerned. This shows that if the maximum gust in a sample of a certain size is measured then the maximum likely in larger samples can be estimated by assuming a normal distribution and using the appropriate ratio. Almost equivalent to this is the statement that if the maximum gust in a certain period of time is measured then the maximum likely in a longer period can be estimated.

Table II*(a)* gives an indication of the errors obtained in using the normal assumption in practice. For each Run, the maximum positive deviation of $(U_{300}-U_T)$ from the mean was found for consecutive samples of 8 and for the larger samples, each of these starting with the sample of 8. The values obtained were compared with those predicted — using the ratios shown in the normal curve in Figure 4 — from the data of the sample of 8. The table shows that, apart from some large errors in Run 5, the errors in all other forecasts are within the range ± 2 m/s.

TABLE II(*a*)—ERRORS IN THE MAXIMUM DEVIATION OF $U_{300}-U_T$ FROM THE MEAN IN VARIOUS SAMPLES AS PREDICTED* FROM THE DATA OF A SAMPLE OF 8

Run number	Maximum deviation of $U_{300}-U_T$ from the mean				Predicted maximum deviation minus actual		
	Sample of 8	Sample of 16	Sample of 24	Sample of 32	Sample of 16	Sample of 24	Sample of 32
	metres per second				*metres per second*		
1	1·17	1·17	1·17	1·17	0·39	0·59	0·73
	−0·60	1·07	1·07	1·50	−0·27	−0·17	−0·53
	1·07	1·07	1·50	1·50	0·35	0·11	0·23
	0·62	1·50	1·50	1·50	−0·68	−0·57	−0·50
2	2·10	2·10	2·10	2·10	0·69	1·05	1·30
	2·03	2·03	2·03	2·03	0·67	1·02	1·26
	0·84	0·84	0·84	0·84	0·28	0·42	0·52
	0·56	0·56	0·74	1·36	0·18	0·10	−0·45
	−0·25	0·74	1·36	1·69	−0·41	−0·98	−1·28
3	0·20	0·46	2·03	2·03	−0·19	−1·73	−1·71
	0·46	2·03	2·03	2·03	−1·42	−1·34	−1·28
	2·03	2·03	2·03	2·03	0·67	1·02	−1·26
	0·98	0·98	0·98	1·11	0·32	0·49	0·48
4	0·15	1·11	1·13	1·49	−0·91	−0·90	−1·25
	1·11	1·13	1·49	1·49	0·35	0·18	0·31
	1·13	1·49	1·49	1·49	0·01	0·21	0·34
5	4·83	4·83	4·83	4·83	1·59	2·42	2·99
	4·47	4·47	4·47	4·47	1·48	2·24	2·77
	1·31	1·31	1·31	1·31	0·43	0·66	0·81
	0·41	0·41	0·41	0·41	0·14	0·21	0·25
	−0·53	0·34	0·34	0·34	0·36	0·46	0·52
	0·34	0·34	0·34	0·44	0·11	0·17	0·11
6	2·79	2·79	2·79	2·79	0·92	1·40	1·73
	0·97	0·97	1·58	1·58	0·32	−0·12	−0·01
	0·28	1·58	1·58	1·58	−1·21	−1·16	−1·13
	1·58	1·58	1·58	1·58	0·52	0·79	0·98
	0·83	1·33	1·33	1·33	−0·23	−0·08	0·01

* By multiplying by a factor based on the probable maximum values in a sample size if distribution is normal.

$(U_{300}-U_T)_m$ is the mean value of $(U_{300}-U_T)$ over the whole Run which it is to be hoped will be approximately zero. Table II(*b*) shows the errors that would occur if the mean were assumed to be zero, i.e. just considering the maximum value in a sample and not subtracting $(U_{300}-U_T)_m$. The table shows that this compares favourably on the whole with the first method on these occasions.

Comparison of different sampling periods (distances). The Cardington data consist of a read-out every second, each being in fact a mean over about 0·9 seconds. The first 45 minutes of each Run were divided into a number of consecutive periods of T seconds duration, and the mean wind V_T in each T-second period was found. The maximum departures from V_T of the 1-second values and means of runs of wind over 40, 100, 200, 300, and 400 m were found for each period T. By dividing each run of wind by the mean wind over the whole 45 minutes, the approximate equivalent number of seconds, t, was obtained for each run-of-wind distance.

The mean wind speed over t seconds may be written

$$V_t = V_T + v_t,$$

where V_T is, as defined above, the mean wind speed over a longer period T, and v_t is the mean deviation from V_T over the period t seconds. Let v_t (max)

TABLE II(*b*)—ERRORS IN THE MAXIMUM DIFFERENCE $U_{300}-U_T$ IN VARIOUS SAMPLES AS PREDICTED* FROM THE DATA FOR A SAMPLE OF 8

Run number	Maximum difference Sample of 8	Predicted maximum difference minus actual Sample of 16	Sample of 24	Sample of 32
		metres per second		
1	1·43	0·47	0·72	0·89
	−0·34	−0·88	−0·82	1·21
	1·33	0·44	0·24	0·39
	0·88	−0·59	−0·44	−0·33
2	1·74	0·57	0·87	1·08
	1·67	0·55	0·84	1·03
	0·48	0·16	0·24	0·30
	0·20	0·07	−0·08	−0·68
	−0·61	0·43	−0·08	−0·34
3	0·05	−0·24	−1·80	−1·80
	0·31	−1·47	−1·41	−1·38
	1·88	0·62	0·94	1·17
	0·83	0·27	0·42	0·37
4	−0·25	−0·38	−0·35	−0·69
	0·71	0·21	−0·02	0·06
	0·73	−0·12	0·10	0·09
5	5·40	1·78	2·70	3·35
	5·04	1·66	2·52	3·12
	1·88	0·62	0·94	1·17
	0·98	0·32	0·49	0·61
	0·04	−0·86	−0·85	−0·85
	0·91	0·30	0·46	0·46
6	2·59	0·85	1·30	1·61
	0·77	0·25	−0·22	−0·13
	0·08	−1·27	−1·26	−1·25
	1·38	0·46	0·69	0·86
	0·63	−0·29	−0·18	−0·11

* By multiplying by a factor based on the probable maximum values in a sample size if distribution is normal.

be the maximum value of v_t during a sample duration of T seconds. To compare different sizes of gusts, the ratio $R(T, t: \theta, s)$ may be used. This is defined as

$$R(T, t: \theta, s) = \frac{v_{T,t}\,(\max)}{v_{\theta,s}\,(\max)},$$

where θ, s are respectively sample durations and averaging times, which may not be the same as T and t (Brook and Spillane[5]).

In the Runs considered 100 metres is approximately equivalent to $12\frac{1}{2}$ seconds for the wind speeds, so the ratio $R(T, t: T, 12\frac{1}{2})$ was calculated for each period T, where t is the number of seconds equivalent to a run of wind. As the 1-second value is actually a mean over about 0·9 seconds, the value of t in this case was taken to be 0·9. Two values of T were considered, $4\frac{1}{2}$ minutes and 9 minutes, and for each Run there were ten $4\frac{1}{2}$-minute periods and five 9-minute periods. The mean values of the ratios for $T = 270$ seconds and $T = 540$ seconds were found for each value of t and for each Run, and the results compared with those obtained by Brook and Spillane which were worked out on the basis of 't-second gusts' and not runs of wind (Figures 6 and 7). The Brook and Spillane points in Figures 6 and 7 were obtained from Figure 4c in their paper, which gives values of the ratio $R(T, t: T, 5)$. Two graphs were drawn, one for $R(270, t: 270, 5)$ and one for $R(540, t: 540, 5)$,

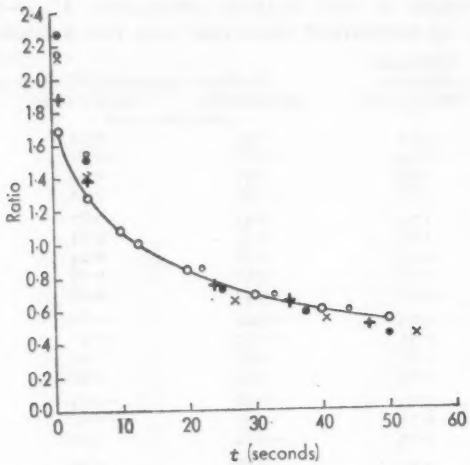

FIGURE 6—RATIOS OF MAXIMUM DEPARTURES FROM THE 4½-MINUTE MEAN WIND OF MEANS OVER t SECONDS TO THE MEAN OVER A 100-METRE RUN OF WIND

–o– Predicted values from Brook and Spillane[5]
\+ Measured values from Cardington Run No. 2
• Measured values from Cardington Run No. 3
× Measured values from Cardington Run No. 4
o Measured values from Cardington Run No. 5

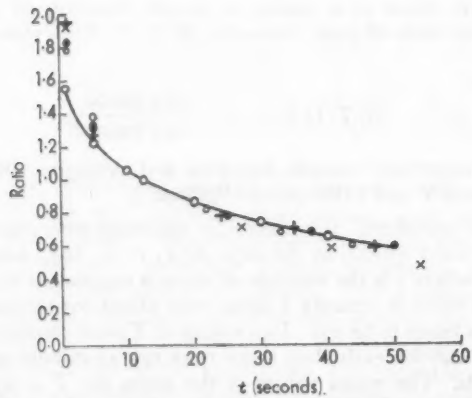

FIGURE 7—RATIOS OF MAXIMUM DEPARTURES FROM THE 9-MINUTE MEAN WIND OF MEANS OVER t SECONDS TO THE MEAN OVER A 100-METRE RUN OF WIND

–o– Predicted values from Brook and Spillane[5]
\+ Measured values from Cardington Run No. 2
• Measured values from Cardington Run No. 3
× Measured values from Cardington Run No. 4
o Measured values from Cardington Run No. 5

and the two values of $R(T, 12\frac{1}{2}: T, 5)$ obtained from the graphs. By dividing the Brook and Spillane values of $R(T, t: T, 5)$ by the obtained value of $R(T, 12: T, 5)$ the required ratios $R(T, t: T, 12\frac{1}{2})$ were obtained, and these are plotted in Figures 6 and 7. The agreement in both cases is very good, the 9-minute results being perhaps slightly better than the others. However, in both cases, the ratios obtained from the Cardington data are greater than those of Brook and Spillane for values of t of 1 second and 5 seconds. This is almost certainly due to the presence of high-frequency 'noise' in the Cardington data. Thus, if the maximum departure of one sample from the mean wind over, say, 9 minutes can be measured, the maximum departure of other sample lengths can be estimated.

Conclusion. A pilot can be given information which will give him an estimate of the mean speed and variability of the wind 10 minutes later. A mean wind speed measured over $4\frac{1}{2}$ minutes gives a reasonable estimate of the mean speed over a 300-m run of wind 10 minutes later. If the maximum departure of $(U_{300}-U_T)$ from the mean were measured over a short period, the maximum likely in a longer period could be estimated, assuming a normal distribution and using the appropriate ratio; for example, if the maximum in a sample of 8, i.e. about 4 minutes, were measured, then multiplication by a factor 1·62 would give an estimate of the maximum likely to occur in a sample of 32, i.e. about 16 minutes which would include the time for the sample of 8 and the 10-minute period before the aircraft reaches the critical position, as well as the actual period of descent from 30 m to 15 m and then on to touch-down. The maximum gust appropriate to different aircraft sampling could also be estimated, using the methods of Brook and Spillane.

The results outlined above are based on one day's observations only.

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551·553.6(729)

EXTREME WIND SPEEDS IN THE COMMONWEALTH CARIBBEAN

By H. C. SHELLARD

Summary. A short description is given of Thom's method of estimating the frequency of extreme winds. The method does not require data over a long period and is based on the expression $G(v)$ for the mixed Fréchet type distribution of the extreme value v, where $G(v) = p_E \exp[-(v/\beta)^{-9}] + p_T \exp[-(v/\beta)^{-4\cdot5}]$ in which the first term allows for extratropical storms and the second for tropical storms. p_E and p_T are the probabilities of an annual extreme being produced by an extratropical and a tropical storm respectively, and $p_E = 1 - p_T$. The parameter β is related to the highest average monthly mean wind speed.

An example is given of the detailed computation of the extreme-value wind distribution for Seawell, Barbados. For a selection of stations in the Caribbean, tables are given indicating

'fastest mile' speeds and some corresponding maximum 3-second gust speeds, for various return periods. The British Standard Code of Practice on Wind Loading has adopted the maximum 3-second gust speed at 10 metres with a return period of 50 years as the basic wind speed for design purposes and corresponding basic design speeds are given for various Caribbean countries.

Introduction. For the design of buildings and other structures the engineer requires information on the statistical probability of short-duration wind speeds. Ideally, rational design wind speeds should be based on the statistical analysis of suitable wind speed recordings covering periods of 20 years or more from a well-distributed network of meteorological stations. Unfortunately such data are available for only very few parts of the world.

In the Commonwealth Caribbean, suitable wind records for the purpose are currently being obtained and, in some cases, have been available for quite a number of years. Until recently, however, few of these records have been subjected to routine measurement and tabulation and even if some of the longer records could be located and analysed it is fairly certain that no homogeneous set of records covering a sufficiently long period would result.

Thus, if estimates of extreme wind speeds having stated probabilities are to be obtained for the Commonwealth Caribbean area now, some alternative procedure must be used. Fortunately such a procedure has been developed by Thom[1] and this paper is concerned with the application of his method to places in the Caribbean and the presentation of the results.

The quasi-universal extreme wind distribution (Thom). Extreme-value wind distributions that have been established for areas with suitable long-period records, such as the U.S.A. (Thom[2]) and the U.K. (Shellard[3,4]), are determined by two parameters: a shape parameter γ and a scale parameter β. The shape parameter defines the shape of the frequency distribution and the scale parameter determines the wind speeds themselves. Thom has shown that for extratropical storms and thunderstorms in the U.S.A. the Fréchet distribution of the extreme value v,

$$F(v) = \exp[-(v/\beta)^{-\gamma}], \qquad \ldots (1)$$

has a shape parameter γ which approaches a value of 9 as record length increases. He also found that the scale parameter β is well correlated with the highest average monthly mean wind speed. Hence a method of approximating the extreme wind distribution in extratropical storm areas was obtained. When the limited data available for tropical storm areas were examined Thom found that the scale parameter could be estimated in the same way as for extratropical storms but that the shape parameter was only about half that found for extratropical storms. This result was based on data from nine stations, only three of which, Miami (Florida), San Juan (Puerto Rico) and Hong Kong, had records covering more than 20 years. Nevertheless, Thom concluded, very reasonably, that since in the southern North Atlantic and the Caribbean some of the annual extreme wind speeds are due to extratropical storms (or thunderstorms) the annual extreme population will be a mixture of extremes from tropical and extratropical storms, giving a mixed extreme-value distribution function :

$$G(v) = p_E F_E(v) + p_T F_T(v), \qquad \ldots (2)$$

where $$F_E(v) = \exp[-(v/\beta)^{-9}], \quad \ldots (3)$$

$$F_T(v) = \exp[-(v/\beta)^{-4.5}] \quad \ldots (4)$$

and $$p_E = 1 - p_T, \quad \ldots (5)$$

where p_E and p_T are the probability of an annual extreme wind being produced by an extratropical and a tropical storm, respectively. He went on to show that p_T could be estimated from the mean number of tropical storm passages per year through the area concerned and presented a map of this parameter (Figure 3 of Thom's paper[1]), covering the southern North Atlantic and the Caribbean and based on storm tracks for the years 1901–63.

The relationships between β and v_m, the highest average monthly mean wind speed, and between p_T and f, the mean number of tropical storms per year, established by Thom are :

$$\beta = (320{\cdot}5\, v_m + 248{\cdot}7)^{\frac{1}{2}} - 15{\cdot}7, \quad \ldots (6)$$

$$p_T = 1/[1 + 99 \exp(-3{\cdot}0 f)]. \quad \ldots (7)$$

Application to stations in the Commonwealth Caribbean. Using Thom's results, summarized above, it is clear that an extreme wind distribution can be estimated for any station for which v_m can be computed from available observations of wind speed, or reasonably estimated. Values are given in Table I for a number of stations in the Caribbean, together with the period of records used and the corresponding values of β. Also given are the appropriate values of f taken from Thom's map and the corresponding values of p_T. San Juan was included in Table I so that extremes estimated by this method might be compared with those computed in the more usual way (analysis of the annual extremes over a long period) and given by Thom in Table 2 of his 1968 paper.[2]

TABLE I—DATA REQUIRED FOR ESTIMATION OF EXTREME WIND DISTRIBUTION FOR CARIBBEAN STATIONS

Station	v_m mile/h	Period	β	f	p_T
San Juan, Puerto Rico	12·9	1940–55	50·5	1·2	0·27
Palisadoes, Jamaica	13·4	1950–62	51·7	1·1	0·22
Coolidge, Antigua	15·0*	1941–48	55·4	1·2	0·27
Seawell, Barbados	16·5	1954–60	58·7	0·9	0·13
Pearls, Grenada	13·0	1954–60	50·7	0·8	0·10
Piarco, Trinidad	8·1	1954–60	37·5	0·7	0·08
East coast, Trinidad	12·0*		48·3	0·7	0·08
Crown Point, Tobago	13·0*		50·7	0·7	0·08

* Estimated.

In three cases the values of v_m were estimated. The only average wind speed datum readily available for Coolidge, Antigua, was an annual average of 13·4 mile/h over the years 1941–48, and 15·0 mile/h is therefore a conservative estimate of the highest average monthly mean wind speed. The mean speed given for Piarco was considered to be unrepresentative of Trinidad for the purpose of estimating a design wind speed since Piarco is rather sheltered and well inland in relation to the prevailing winds. A mean speed some 50 per cent higher was therefore estimated as representative of the east coast and hence of more exposed areas generally in the island, bearing in mind that winds associated with a tropical storm may blow from any direction.

The mean speed given for Crown Point was based on the analysis of 6 months of concurrent hourly wind speeds from Crown Point and Piarco, giving a mean ratio of 1·65 between the two stations.

An example of the detailed computation of a mixed extreme-value wind distribution is given by Thom, but another is given in Table II using the data for Seawell, given in Table I. As Thom indicated, the distribution $G(v)$ must be computed for a series of values of v and the speed that will be exceeded with any desired probability must then be obtained by interpolation. To compute F it is convenient to rearrange equation (1) in the form

$$\ln \ln (1/F) = -\gamma \ln (v/\beta), \qquad \ldots (8)$$

giving

$$1/F = \exp \exp [-\gamma \ln (v/\beta)]. \qquad \ldots (9)$$

Also, since, for Seawell, $\beta = 58{\cdot}7$ and $p_T = 0{\cdot}13$, we have to evaluate the mixed distribution

$$G(v) = 0{\cdot}87 \exp [-(v/58{\cdot}7)^{-9}] + 0{\cdot}13 \exp [-(v/58{\cdot}7)^{-4{\cdot}5}], \qquad \ldots (10)$$

and this is done in Table II for a series of values of v.

TABLE II—COMPUTATION OF MIXED EXTREME WIND DISTRIBUTION FOR SEAWELL, BARBADOS

v mile/h	$\ln(v/58{\cdot}7)$	$-9 \ln(v/58{\cdot}7)$	$-4{\cdot}5 \ln(v/58{\cdot}7)$	$1/F_E$	$1/F_T$	$0{\cdot}87F_E$	$0{\cdot}13F_T$	G
50	−0·1602	1·4418	0·7209	68·7	7·815	0·013	0·017	0·030
60	0·0219	−0·1971	−0·0985	2·273	2·475	0·383	0·053	0·436
80	0·3097	−2·7873	−1·3937	1·063	1·282	0·818	0·101	0·919
100	0·5327	−4·7943	−2·3971	1·008	1·095	0·863	0·118	0·981
120	0·7149	−6·4341	−3·2171	1·002	1·041	0·869	0·125	0·994

The values of v and G may be plotted on extreme-value probability paper as in Figure 1, from which the speed corresponding to any desired cumulative probability (or return period) may be read off. For example, the speed

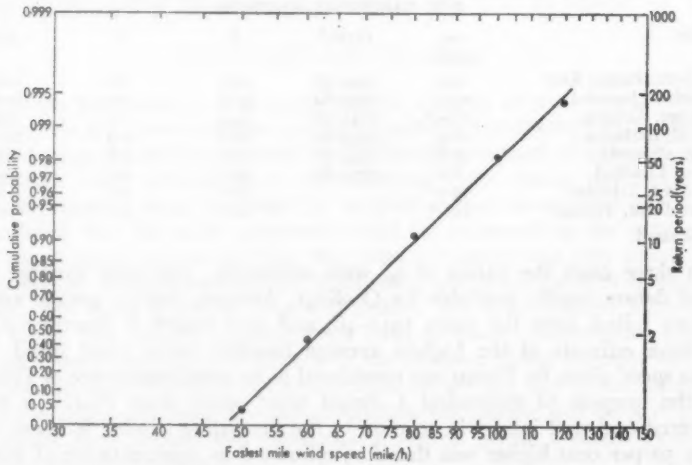

FIGURE 1—ESTIMATED FRÉCHET EXTREME WIND DISTRIBUTION, SEAWELL, BARBADOS

having a cumulative probability of $G = 0{\cdot}98$ is 100 mile/h. In other words a wind speed of 100 mile/h at Seawell is likely to be exceeded on the average only once in 50 years.

Similar computations have been carried out for all the places listed in Table I with the results set out in Table III. It is important to emphasize here that these speeds are 'fastest mile' speeds, i.e. they are estimates of the fastest mile of wind. This is because Thom's distribution is based on observations made in the U.S.A., where the extreme wind speed variable that is most widely available is the fastest mile. The values given in brackets on the first line of Table III are the Puerto Rico fastest mile values published by Thom[2] and mentioned earlier. It will be noted that the agreement between the two sets of values is quite good.

TABLE III—FASTEST MILE SPEEDS* FOR RETURN PERIODS OF 10, 20, 25, 50, 100 AND 200 YEARS

	Return period (years)					
	10	20	25	50	100	200
	mile/h					
San Juan, Puerto Rico	72(65)	80	83(80)	94(95)	105(110)	118
Palisadoes, Jamaica	71	79	83	93	105	117
Coolidge, Antigua	78	88	91	102	113	126
Seawell, Barbados	79	88	91	100	110	121
Pearls, Grenada	67	74	77	85	94	104
Piarco, Trinidad	48	54	56	63	69	77
East coast, Trinidad	63	69	72	78	86	93
Crown Point, Tobago	67	74	77	85	93	103

* The speeds given in mile/h can be converted to knots by multiplying by 0·868, and to metres/seconds by multiplying by 0·447.

Figures in brackets are the Puerto Rico fastest mile values published by Thom.[2]

In the West Indies the fastest mile of wind is not normally measured and the British practice of extracting the highest hourly mean speed and the highest gust speed for each day is generally followed. The anemographs in most general use have response characteristics such that the maximum gust speed is equivalent to a speed averaged over a period of approximately 3 seconds. The fastest mile speeds given in Table III may be converted into their equivalent 3-second gust speeds, by making use of experimental measurements that are available on the relationship between wind speeds averaged over different periods of time. Such measurements, over open level country, have been made, for example, at Cardington, England (Durst[5]), and at Sale, Australia (Deacon[6]), the two sets of results being in excellent agreement. By making use of these and remembering that v mile/h is equivalent to a speed averaged over $60/v$ minutes (or $3600/v$ seconds), a simple relationship can be deduced between the fastest mile speed *(v)* and the corresponding 3-second gust speed *(g)*. This relationship is :

$$g_3^* = 1{\cdot}09\, v + 8 \text{ mile/h.} \qquad \ldots (11)$$

Hence the maximum (3-second) gust speeds corresponding to the fastest mile speeds of Table III may be calculated and these are set out in Table IV, which thus gives estimated maximum gust speeds for places in the Commonwealth Caribbean for return periods of 10, 20, 50 and 100 years.

TABLE IV—MAXIMUM GUST SPEEDS FOR RETURN PERIODS OF 10, 25, 50 AND 100 YEARS

	Return period (years)			
	10	20	50	100
	mile/h			
Palisadoes, Jamaica	85	94	110	123
Coolidge, Antigua	93	104	120	132
Seawell, Barbados	94	104	117	128
Pearls, Grenada	81	89	101	111
Piarco, Trinidad	60	67	76	83
East coast, Trinidad	76	83	93	102
Crown Point, Tobago	81	89	101	110

It may be noted that the British Standard Code of Practice on Wind Loading (*British Standard Code of Practice* 3, Chapter V, Part II, 1970) has adopted the maximum 3-second gust speed at 10 metres (33 ft) above the ground, with return period of 50 years, as the basic wind speed for design purposes. Thus, corresponding basic design wind speeds for some Commonwealth Caribbean countries, based on the figures in column 4 of Table IV, might be suggested for adoption in any new code of practice for use in the area, as indicated in Table V.

TABLE V—SUGGESTED BASIC DESIGN WIND SPEEDS FOR SOME COMMONWEALTH CARIBBEAN COUNTRIES

	mile/h
Jamaica Leeward and British Virgin Islands Barbados, St Vincent, St Lucia	120
Grenada, Tobago	100
Trinidad	90
Guyana	50

In the last line of this table a figure of 50 mile/h has been inserted for Guyana, which is not affected by tropical storms. This is based on the fact that in a record commencing in 1927, the highest gust speed recorded at Georgetown (Botanic Gardens) was one of 43 mile/h.

Finally, in view of the fact that wind speeds of 150 to 160 mile/h have been measured in well-developed hurricanes, and these are means over periods of a minute or longer, it might be thought that the speeds in Table V are on the low side. However, it must be pointed out that the return period of a well-developed hurricane in any particular place is probably much greater than 50 years. Moreover, an engineer who wishes to design a structure to withstand the full force of a major hurricane may be expected to take this into account, and to use a design wind speed of about 160 mile/h or more, with a return period of perhaps 1000 years, depending on an assessment of the risk of failure in relation to the purpose, probable lifetime and cost of the structure concerned.

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551.509.325:551.591

VISIBILITY DETERIORATIONS DURING WINTER MORNINGS

By W. E. SAUNDERS

Summary. A study of visibility deteriorations on clear winter mornings at a number of aerodromes in eastern England shows that the probability of deterioration varies markedly with the position of a site in relation to smoke sources and low-lying areas. Wind direction is therefore of great importance. The likelihood of deterioration is shown to decrease with increasing wind speed. It is also shown that on the majority of occasions when the lowest visibility reached during the morning did not exceed 2 km the wind was calm or the direction was from smoky or damp, low-lying areas. The time of reaching the lowest visibility is shown to vary from station to station.

It is well known to forecasters that following a clear night, which has been free from fog, visibility frequently decreases during the morning, especially during the winter. This may be due to industrial or domestic smoke, or in some locations to the drift of mist or fog from low-lying or fen areas. In either case, the diurnal increase in wind speed and turbulence after sunrise contributes to the effect.

The records for 10 aerodromes between Northumberland and the Cambridge area (see Figure 1) for the months November to February for five winters (November 1965 to February 1970), were examined in order to assess the incidence of these morning deteriorations. Cases included were those in which at 04 GMT there was no fog and the cloud amount did not exceed 3/8, excluding broken cirrus. The initial time of 04 GMT was selected because this is the last observation available before forecasts require to be issued for many day-time activities. The sunrise times vary between about 0645 and 0830 GMT.

For the purpose of this study, a deterioration was regarded as having occurred if the visibility decreased from within one of the following ranges at 04 GMT into any lower range within the period 06–13 GMT:

1·0 – 1·9 km
2·0 – 3·9 km
4·0 – 8·0 km
over 8 km

Cases where a visibility deterioration was due to precipitation were omitted.

FIGURE 1—MAP OF AREA

o Aerodromes mentioned in text

The overall position regarding deteriorations is given in Table I. This shows considerable consistency north of about York, with deteriorations on around 30 per cent of the clear mornings. The probability of deterioration increases in south Yorkshire, because of the proximity of Church Fenton and Finningley to the smoke sources of the West Riding and urban areas further south, and of the low-lying ground near these aerodromes. However, the difference between the frequency of deteriorations at stations Acklington

TABLE I—INCIDENCE OF DETERIORATIONS IN VISIBILITY BETWEEN 06 AND 13 GMT ON MORNINGS WHICH WERE CLEAR* AT 04 GMT, NOVEMBER 1965 TO FEBRUARY 1970

Station	Number of days clear at 04 GMT	Incidence of deteriorations	
		Number of days	Percentage
Acklington	164	44	27
Leeming	173	51	29
Topcliffe†	133	38	29
Linton-on-Ouse†	105	33	31
Church Fenton†‡	96	56	58
Finningley	189	121	64
Manby	169	89	53
Strubby†	109	41	38
Cranwell†	109	40	37
Oakington†	131	52	40

* No fog and cloud not exceeding 3/8, excluding broken cirrus.
† These stations normally report on Mondays to Fridays only.
‡ At Church Fenton 06 GMT was taken as the initial time instead of 04 GMT.

to Linton-on-Ouse and the frequency at Church Fenton and Finningley is also partly due to the original selection of clear nights. Cloudless weather during the night and early morning is most likely at Acklington and in north Yorkshire with gradient winds from between west and north, and the figures reflect lack of smoke sources within this quadrant for stations down to Linton. Also, of course, these airstreams have crossed the Cheviot and Pennine hills, and are relatively dry. The stations south of Finningley are affected by a variety of smoke sources, and by drift from low-lying ground, but the likelihood of deterioration is rather less than in south Yorkshire.

Table II shows the effect of wind speed on the incidence of deteriorations. In general the probability of deterioration decreases with increasing wind speed.

The effect of wind direction is shown in Table III. For each station, omitting the days of calm, the occasions were separated according to mean wind direction in the period from 06 GMT to the time of lowest visibility; those with wind directions from smoky or low-lying areas were separated from those with 'clean' wind directions. An attempt to separate the smoky occasions from those with drift from low-lying areas by use of a relative-humidity criterion was not satisfactory. Table III shows that wind direction is of great importance at Vale of York stations, especially at Leeming. The results imply that the smoke trails which affect that aerodrome are very sharply defined. South of York the differences due to wind direction become less pronounced.

In Table IV the lowest visibility in the period 06–13 GMT has been tabulated against wind speed, with the mean directions grouped as in Table III. This emphasizes the importance of smoke pollution, or in some cases drift from low-lying ground, in the formation of fog on winter mornings. Out of 129 occasions of morning fog formation, the mean wind direction was from smoky or low-lying directions, or calm, on 115 occasions, and from 'clean' directions on 14 occasions. Similarly, out of 116 occasions when the lowest visibility was 1·0–1·9 km, the mean wind direction was from smoky or low-lying areas, or calm, on 100 occasions, and from 'clean' directions on 16. Even allowing for the fact that there were more total occasions with winds from smoky or low-lying areas, or calm (857), than from 'clean' areas (521), there is the strong implication that pollution is a major factor in deteriorations.

TABLE II—VARIATION OF INCIDENCE OF DETERIORIATIONS IN VISIBILITY BETWEEN 06 AND 13 GMT WITH THE MEAN WIND SPEED BETWEEN 06 GMT AND THE TIME OF LOWEST VISIBILITY ON MORNINGS WHICH WERE CLEAR AT 04 GMT, NOVEMBER 1965 TO FEBRUARY 1970

Station	Calm			1–5 kt			6–9 kt			Over 9 kt		
	Number of days clear at 04 GMT	Incidence of deteriorations Number of days	Incidence of deteriorations Percentage	Number of days clear at 04 GMT	Incidence of deteriorations Number of days	Incidence of deteriorations Percentage	Number of days clear at 04 GMT	Incidence of deteriorations Number of days	Incidence of deteriorations Percentage	Number of days clear at 04 GMT	Incidence of deteriorations Number of days	Incidence of deteriorations Percentage
Acklington	3	3	100	15	12	80	57	21	37	89	8	9
Leeming	20	11	55	37	22	59	39	11	28	77	7	9
Topcliffe	21	8	38	50	18	36	33	10	30	29	2	7
Linton-on-Ouse	25	15	60	24	13	54	23	3	13	33	2	6
Church Fenton	9	8	89	15	9	60	35	23	66	37	16	43
Finningley	20	19	95	19	15	79	62	45	73	88	42	48
Manby	0	0	—	19	12	63	44	28	64	106	49	46
Strubby	2	0	0	6	3	50	36	18	50	65	20	31
Cranwell	6	4	67	15	10	67	38	18	47	50	8	16
Oakington	1	1	—	12	7	58	38	23	61	80	21	26

TABLE III—VARIATION OF INCIDENCE OF DETERIORATIONS IN VISIBILITY BETWEEN 06 AND 13 GMT WITH THE MEAN WIND DIRECTION BETWEEN 06 GMT AND THE TIME OF LOWEST VISIBILITY ON MORNINGS WHICH WERE CLEAR AT 04 GMT, NOVEMBER 1965 TO FEBRUARY 1970

Station	Wind from smoky or damp, low-lying areas				Wind from 'clean' areas			
	Wind direction *degrees true*	Number of days clear at 04 GMT	Incidence of deteriorations		Wind direction *degrees true*	Number of days clear at 04 GMT	Incidence of deteriorations	
			Number of days	Percentage			Number of days	Percentage
Acklington	130–210	18	13	72	220–120	143	28	20
Leeming	140–190 360–060	34	31	91	070–130 200–350	119	9	8
Topcliffe	140–220 340–020	42	20	48	030–130 230–330	70	10	14
Linton-on-Ouse	120–230 330–020	25	11	44	030–110 240–320	55	7	13
Church Fenton	170–270 020–030	34	25	74	040–160 280–010	53	23	43
Finningley	180–330	144	91	63	340–170	25	11	44
Manby	120–360	160	86	54	010–110	9	3	33
Strubby	120–360	105	41	39	010–110	2	0	0
Cranwell	070–160 250–340	83	30	36	170–240 350–060	20	6	30
Oakington	260–210	105	46	44	220–250	25	5	20

TABLE IV—VARIATION OF INCIDENCE OF LOWEST VISIBILITY BETWEEN 06 AND 13 GMT WITH MEAN WIND SPEED AND DIRECTION* ON MORNINGS WHICH WERE CLEAR AT 04 GMT, NOVEMBER 1965 TO FEBRUARY 1970

Station	Calm					Wind from smoky or damp, low-lying areas						Wind from 'clean' areas					
	<1 km	1·0–1·9 km	2·0–3·9 km	4·0–8·0 km	>8 km	Wind speed kt	<1 km	1·0–1·9 km	2·0–3·9 km	4·0–8·0 km	>8 km	Wind speed kt	<1 km	1·0–1·9 km	2·0–3·9 km	4·0–8·0 km	>8 km
	number of occasions						number of occasions						number of occasions				
Acklington	3	—	—	—	—	1–5	2	2	—	—	—	1–5	1	1	3	5	1
						6–9	—	1	—	—	—	6–9	1	1	5	13	36
						>9	1	—	4	4	4	>9	—	—	2	3	71
Leeming	5	4	3	3	5	1–5	9	3	—	6	—	1–5	—	1	1	6	11
						6–9	3	1	2	4	1	6–9	—	—	—	3	25
						>9	—	—	3	1	1	>9	—	—	1	4	67
Topcliffe	5	1	3	4	8	1–5	6	—	4	5	10	1–5	3	2	—	2	18
						6–9	3	—	1	3	3	6–9	1	—	4	1	17
						>9	—	—	3	—	4	>9	—	—	1	1	20
Linton-on-Ouse	8	5	1	6	5	1–5	4	2	3	—	3	1–5	1	1	1	3	6
						6–9	—	2	—	2	1	6–9	—	—	—	2	16
						>9	—	—	1	2	5	>9	—	—	—	1	24
Church Fenton	3	5	1	—	—	1–5	2	1	2	1	—	1–5	2	3	2	1	1
						6–9	1	2	4	3	—	6–9	1	—	7	9	8
						>9	1	3	2	8	4	>9	—	—	—	6	13
Finningley	12	5	2	1	—	1–5	2	5	3	1	—	1–5	2	2	2	2	—
						6–9	6	8	21	14	1	6–9	—	3	2	5	2
						>9	—	1	14	35	33	>9	—	—	1	1	3
Manby	—	—	—	—	—	1–5	8	2	4	2	1	1–5	1	—	—	—	1
						6–9	5	8	6	19	1	6–9	—	—	1	1	3
						>9	—	4	11	53	36	>9	—	—	—	2	—
Strubby	—	—	—	1	1	1–5	—	2	3	1	—	1–5	—	—	—	—	—
						6–9	2	5	16	9	4	6–9	—	—	—	—	—
						>9	2	—	5	31	25	>9	—	—	1	1	—
Cranwell	2	2	—	2	—	1–5	2	4	3	1	—	1–5	1	—	2	2	—
						6–9	4	7	7	7	7	6–9	—	—	3	2	1
						>9	1	1	7	10	22	>9	—	—	2	3	4
Oakington	—	1	—	—	—	1–5	4	5	—	3	—	1–5	—	—	—	—	—
						6–9	7	5	12	8	4	6–9	—	2	—	—	—
						>9	2	3	8	19	25	>9	—	—	6	5	12

* Wind directions are grouped as in Table III.

There is no doubt that the wind directions which have been taken as basically 'clean' in this investigation often carry some pollution from minor sources, and it is important in forecasting to identify and allow for these sources. It is also true that topographical effects sometimes lead to smoke arriving at an aerodrome from a direction which is normally 'clean'. For example, at Topcliffe the wind direction for arrival of West Riding smoke is normally 180–220°, but with light winds under a winter inversion the smoke may reach the station from the south-east, having been confined to the east side of the Vale of York by high ground further east.

In Table V, the time of reaching the lowest visibility within the period 06–13 GMT has been related to certain wind directions for a selection of stations. For Leeming, with wind directions which bring West Riding smoke, there are maxima at 07–08 and 11–12 GMT. For Finningley, with winds from smoky or low-lying directions, there is a pronounced maximum of lowest visibility between 08 and 10 GMT. For Manby, the times have been given separately for the direction bands 010–170° (wind off the sea, or from damp,

TABLE V—VARIATION OF TIME OF INCIDENCE OF LOWEST VISIBILITY IN PERIOD 06 TO 13 GMT WITH CERTAIN WIND DIRECTIONS ON MORNINGS WHICH WERE CLEAR AT 04 GMT, NOVEMBER 1965 TO JANUARY 1970

Station	Mean wind direction *degrees true*	Time of lowest visibility, GMT: 06–07	07–08	08–09	09–10	10–11	11–12	12–13
		Incidence of lowest visibility (number of days)						
Leeming	140–190	2	6	3	2	1	8	5
Finningley	180–330	22	19	41	47	5	1	5
Manby	010–170	14	2	4	1	—	5	—
	280–360	16	7	11	12	2	9	14

low-lying ground), and from 280–360° (predominantly smoky). This shows that with direction 010–170° the lowest visibility is reached in the early morning, but that with 280–360° there are maxima at later times, including one as late as 12–13 GMT. This emphasizes that deteriorations due to smoke from remote sources tend to occur in the late morning.

Acknowledgement. The author is indebted to outstation staff for their considered opinions on the smoke sources, and for extracting the data.

551.554:551.556:551.453

SAND STREETS

By J. D. HASTINGS

Summary. During a flight over a 'ghibli' between El Adem (Libya) and the coast on the morning of 14 February 1969, it was noticed that lines were visible below in the rising sand in a number of places. The lines were analogous to cloud streets aligned in the direction of the winds.

It is suggested that what had been observed was the process of longitudinal dune formation in action. Study of the upper air data for that day shows that the diameter of helical eddies would have been about 300 m and the spacing between them 600 m to 900 m, that is to say about half a nautical mile.

A Hercules aircraft of Air Support Command took off from RAF El Adem at about 0930 GMT on 14 February 1969 in conditions known locally as

'ghibli', i.e. the south-south-easterly winds were gusting at times to 40 kt* and visibility was reduced to a few hundred metres by rising sand. Not long after take-off when permission was given to release seat belts and when as far as could be estimated the aircraft was approaching the Jebel Akhdar to the south of Derna at a height of 10 000 ft, it was noticed on looking out of the port-side window that lines showed up quite clearly in the rising sand below; they occurred in a number of places and appeared to be aligned along the direction of the winds. Unfortunately, external vision is very limited in a Hercules aircraft except from the flight deck so it was not possible to form any idea of how widespread the phenomenon was, nor was there a camera readily available to photograph it.

Initial reaction was to speculate whether the phenomenon showed up on pictures by automatic picture transmission (APT) but although an examination was made at El Adem of such pictures of the area on occasions of ghibli going back almost a year, it proved quite fruitless. At the time it was not appreciated that the distance between the streets (approximately 0·5 to 1 km) would be so much less than the present resolution (4 km) of the satellite cameras. Later in the year while attempting to explain the phenomenon, not entirely satisfactorily, on the basis of 'thermal streeting' (Konrad[1]) the author's attention was drawn to a paper by Hanna.[2] In it he states that satellites orbiting 200 to 300 km above the earth have confirmed the presence of longitudinal dune systems in nearly every large desert area of the world.

Satellite pictures show the dunes aligned north-north-west to south-south-east over Libya and Egypt, turning north-east to south-west over Chad and the Sudan. This direction over Libya is in accord with statistics which show that for El Adem 50 per cent of winds at 06 and 12 GMT of force four or more are from 330/360° and 11 per cent from 150/180°. The spacing over the Fezzan is estimated to be 2 to 3 km but in general over the world the average is 1 to 2 km.

Longitudinal vortices have been observed in the motion of neutral-lift balloons. Angell *et alii*[3] observed helical circulations of 600-m diameter over the Los Angeles basin and in 1968[4] noted counter-rotating helical circulations over the Idaho desert having a diameter of 1·5 to 2·5 km.

Cloud-street spacings appear to range from 0·5 km to as much as 30 km. Kuettner[5] made a thorough investigation into cloud streeting and found the average spacing to be between 5 and 10 km, a value usually twice to three times the depth of the convective layer. He gives the following conditions as conducive to streeting :

(i) flat underlying terrain,
(ii) little variation of wind direction with height,
(iii) wind speed higher than normal,
(iv) strong curvature of wind-speed profile, and
(v) unstable lapse rate close to the surface (and an inversion at the top of the convective layer).

* Conversion factors to metric units are : 1 knot≈0·5 m/s; 1 foot = 0·3048 m.

When these conditions are met the dominant form of motion in the convective layer is a longitudinal roll vortex approximately parallel to the mean flow and having a wavelength about twice the thickness of the layer.

After considering alternative approaches to the problem of helical eddy formation Hanna believes Kuettner's theory to be the most applicable to the boundary layer of desert areas. The process envisaged is shown in Figure 1.

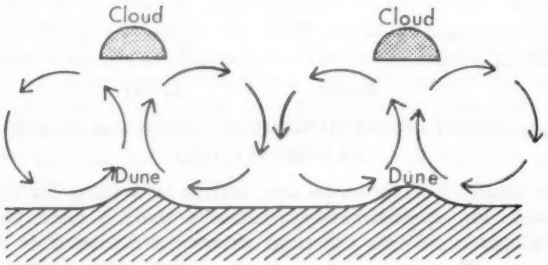

FIGURE 1—MECHANISM OF DUNE AND CLOUD FORMATION

It was therefore decided to see how well Kuettner's five conditions were satisfied on the occasion when the sand streets were noted. The wind profiles for El Adem for 05 GMT and Tobruk for 00, 06 and 12 GMT are shown in Figure 2. For comparison the mean wind profile found by Kuettner for cloud streeting is included. The ascents from Tobruk for 00 and 12 GMT are given in Figure 3.

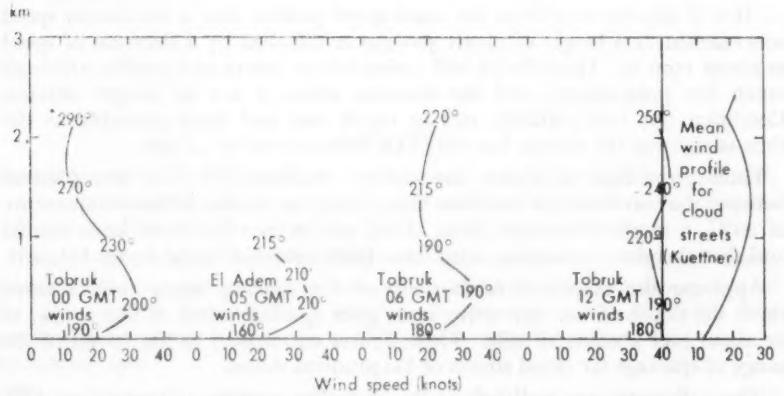

FIGURE 2—WIND PROFILES FOR TOBRUK AND EL ADEM, 14 FEBRUARY 1969

Hanna has noted that the wind must pass over a minimum distance of flat surface before longitudinal vortices will develop and, using the time period T of the circulations within observed vortices of about 2000 s and a

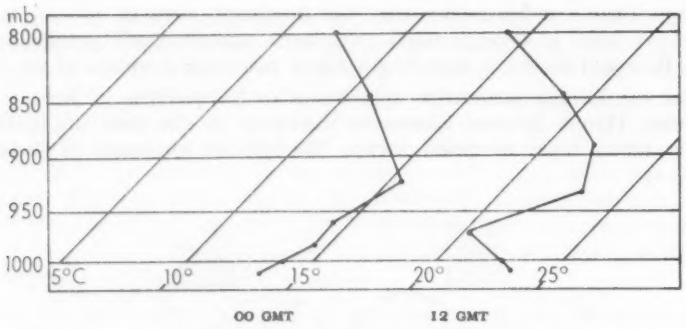

FIGURE 3—ASCENT TEMPERATURES FROM TOBRUK FOR 00 AND 12 GMT, 14 FEBRUARY 1969

typical wind speed U of about 10 m/s, arrives at a value for this minimum of $T \times U = 20$ km approximately. Although there is some uncertainty as to the exact location where the sand streets were seen it is thought that condition (i) as well as the requirement of a 'fetch' of more than 20 km were both satisfied.

From the wind-speed profiles it will be seen that at both El Adem and Tobruk at 06 GMT in particular, there is only a small variation of direction with height in the lowest kilometre. By 12 GMT although direction is still unchanged in the lowest half kilometre a veer of 30° has taken place at 1 km and above. Condition (ii) is however met within the convective layer.

Surface winds at El Adem and Tobruk were 20 kt at 05/06 GMT and had increased to 25/30 kt with gusts to 40 kt from 160° by 09 GMT. Condition (iii) is evidently satisfied.

It will also be seen from the wind-speed profiles that a maximum speed was reached at a height of about 300/450 m followed by a decrease of speed to about 1500 m. This effect is still noticeable on the 12 GMT profile, although much less pronounced, and the decrease above 1 km no longer obtains. Condition (iv) was certainly met at 05/06 GMT and most probably at the time of sighting the streets, but only to a lesser extent by 12 GMT.

Finally, the lapse rate near the surface, condition (v) : by interpolation between the two ascents it is evident that, taking the 09 GMT surface temperature of 20°C, a marked inversion from about 300 m to 1 km must have existed and that therefore convection must have been restricted to the layers below it.

Applying the empirical relationship of the spacing being two to three times the depth of the convective layer gives spacing values of 600 to 900 m or about half a nautical mile. These figures correspond to the lowest of the range of spacings for cloud streets or longitudinal dunes.

These distances are well below the resolution possible at present on APT pictures but not on high-level aerial photographs such as made from Gemini spacecraft. The National Aeronautical Space Administration (NASA) Manned Spacecraft Centre at Houston, Texas, provided three colour transparencies of the south-west of Libya which were the only photographic coverage available of the country. An approach was then made to the Joint Air

Reconnaissance Interpretation Centre (JARIC) but again, unfortunately, without success. Finally however, a series of photographs covering the area was obtained from the Survey Liaison Staff (UK) Royal Engineers (SLS (UK)RE) from which it was evident both to skilled and unskilled eyes that no permanent dune formations could be seen at least at the time that the photographs were taken.

From the most recent maps and from personal knowledge of the area it is apparent that while there is sufficient sand to produce serious deteriorations of visibility with strong winds it is not enough for permanent dunes to form. Any which did during the period of a ghibli could be expected to be of little vertical extent and of a temporary nature, being easily destroyed subsequently by winds blowing from another direction. Nevertheless, it has been shown that the conditions for longitudinal dune formation as postulated by Hanna were satisfied on the morning of 14 February 1969 and it is suggested that what appeared to be sand streets was, in all probability, this process as it would appear from above.

The author would like to acknowledge with thanks the transparencies provided by NASA and the help given by both JARIC and SLS(UK)RE.

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REVIEW

Atmospheric optics (translated from the Russian), edited by Nikolai B. Divari. 270 mm × 210 mm, pp. 191, *illus.*, Consultants Bureau, London, Donnington House, 30 Norfolk Street, London WC2, 1970. Price: $27·50.

This book contains the proceedings of conferences on atmospheric optics sponsored by the committee on the optical instabliity of the atmosphere of the Astronomical Council of the Academy of Sciences of the U.S.S.R. The meetings were held in Pulkovo in November and December 1965 and in November 1966.

There are 31 short papers, about 10 of which are of mainly astronomical interest. The remainder deal with atmospheric transmission coefficients, atmospheric scattering, spectral brightness of the sky, polarization and twilight phenomena, including the evaluation of dust in the upper atmosphere by the twilight method.

J. PATON

OBITUARIES

It is with regret that we record the death on 10 February 1971, of Mr H. J. Groom, Experimental Officer, Met O 8, and the death on 5 February 1971, of Mr J. W. Armstrong, Senior Scientific Assistant, Acklington.

OFFICIAL PUBLICATIONS

Geophysical Memoirs

No. 113. An observational study of the meridional flux of energy and angular momentum in the troposphere and lower stratosphere at latitude 30°N using 1958 IGY data. By A. E. Parker.

This memoir discusses the results of the calculations made from information amassed during the International Geophysical Year, 1958, concerning the transport of momentum, heat and energy northwards across latitude 30°N. Four months — March, June, September and December — were chosen as being the most representative for the year.

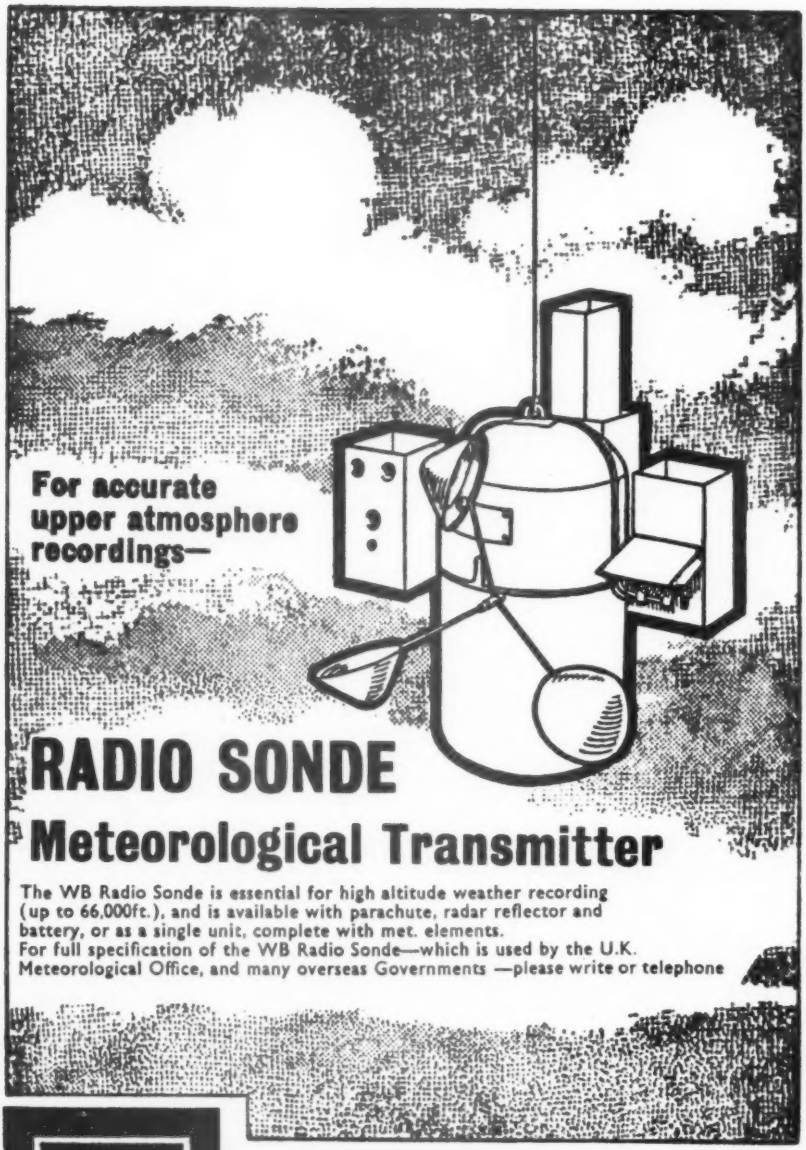
Scientific Paper

No. 31. The three-dimensional analysis of meteorological data. By R. Dixon, B.Sc. and E. A. Spackman, M.Sc.

Before meteorological observations can be used by a computer for the purpose of forecasting the weather, the raw observations have to be processed within the computer so that they can serve as initial data for the mathematical model of the atmosphere which actually does the forecasting. The advent of modern observational devices such as satellites and long-life free drifting balloons has greatly complicated the process of data analysis by computer. This paper presents a possible method for effecting this data analysis by fitting a high-power polynomial to all the observations from within a large volume of the atmosphere.

The following publication has recently been issued : *Monthly charts of dew-point temperatures over the Indian Ocean.*

This publication consists of charts of the mean and the 95 and 5 percentile surface dew-point temperatures over the Indian Ocean for each month of the year. It is an addition to *Monthly meteorological charts of the Indian Ocean* (HMSO, 1949). These dew-point temperature charts were prepared from punched cards of ships' observations, mainly British, for the period April 1953 to December 1961. This representation of humidity will be useful to shippers and packers who are concerned with problems of cargo ventilation in the Indian Ocean area.



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CONTENTS

Page

A note on the optimum averaging time of wind information for conventional aircraft landings. W. R. Sparks and Barbara Keddie 129

Some aspects of wind information required in the landing of aircraft. Barbara Keddie 134

Extreme wind speeds in the Commonwealth Caribbean. H. C. Shellard 143

Visibility deteriorations during winter mornings. W. E. Saunders 149

Sand streets. J. D. Hastings 155

Review

Atmospheric optics. N. B. Divari, Editor. *J. Paton* 159

Obituaries 160

Official publications 160

NOTICES

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